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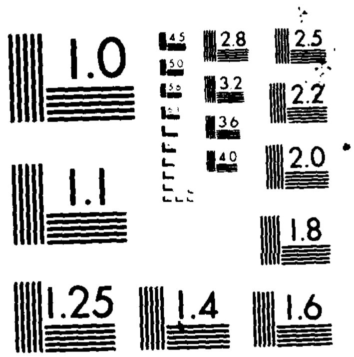

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A temperate environment heat tolerance test (HTT) was formerly reported (Shvartz et al. 1977b) to distinguish heat acclimatized humans from former heat stroke patients. The purpose of this investigation was to evaluate the ability of HTT to measure acute individual changes in the heat tolerance of normal subjects, brought about by classical heat acclimation procedures, thereby assessing the utility and sensitivity of HTT as a heat tolerance screening procedure. On day 1, fourteen healthy males performed HTT (23.2 ± 0.5°C db, 14.9 ± 0.5°C wb) by bench stepping (30 cm high, 27 steps.min^{-1}) for 15 min at 67 ± 3% VO_2 max.

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On days 2 - 9, all subjects underwent heat acclimation (41.2 ± 0.3°C db, 28.4 ± 0.3°C wb) via treadmill exercise. Heat acclimation trials (day 2 vs day 9) resulted in significant decreases in HR (170 ± 3 vs 144 ± 5 beats.min^{-1}), Tre (39.21 ± 0.09 vs 38.56 ± 0.17°C), and ratings of perceived exertion; plasma volume expanded 5.2 ± 1.7%. On day 10, subjects repeated HTT; day 1 vs day 10 HR were statistically similar (143 ± 6 vs 137 ± 6 beats.min^{-1}, $p > .05$) but Tre decreased significantly (37.7 ± 0.1 vs 37.5 ± 0.1°C, $p < .05$). Group mean HTT composite score (day 1 vs day 10) was unchanged (63 ± 5 vs 72 ± 6, $p > .05$), and individual composite scores indicated that HTT did not accurately measure HR and Tre trends at 41.2°C in 6 out of 14 subjects. Among the physical characteristics of subjects, only VO_2max correlated strongly ($r^2 = .74$, $p < .001$) with HTT, indicating a large aerobic component. We concluded that HTT is not a substitute for classical heat tolerance tests conducted at high ambient temperatures. HTT is apparently most useful in patient or at-risk populations in which preliminary or gross distinctions between heat tolerant and heat intolerant individuals are required.

Evaluation of a temperate environment heat tolerance test

Authors: Lawrence E. Armstrong
Roger W. Hubbard
Jane P. DeLuca
Elaine L. Christensen
William J. Kraemer

Institution: U. S. Army Research Institute of Environmental Medicine
Heat Research Division and Exercise Physiology Division
Kansas St.
Natick, MA 01760-5007

Correspondence: Lawrence E. Armstrong, Ph.D.
Research Physiologist

Running Head: Heat Tolerance Test Evaluation

[3 tables, 1 figure]

Evaluation of a temperate environment
heat tolerance test

[3 tables, 1 figure]

Summary

A temperate environment heat tolerance test (HTT) was formerly reported (Shvartz et al. 1977b) to distinguish heat acclimatized humans from former heat stroke patients. The purpose of this investigation was to evaluate the ability of HTT to measure acute individual changes in the heat tolerance of normal subjects, brought about by classical heat acclimation procedures, thereby assessing the utility and sensitivity of HTT as a heat tolerance screening procedure. On day 1, fourteen healthy males performed HTT ($23.2 \pm 0.5^{o}C$ db, $14.9 \pm 0.5^{o}C$ wb) by bench stepping (30 cm high, 27 steps$\cdot min^{-1}$) for 15 min at 67 ± 3 %VO_2max. On days 2 - 9, all subjects underwent heat acclimation ($41.2 \pm 0.3^{o}C$ db, $28.4 \pm 0.3^{o}C$ wb) via treadmill exercise. Heat acclimation trials (day 2 vs day 9) resulted in significant decreases in HR (170 ± 3 vs 144 ± 5 beats$\cdot min^{-1}$), Tre (39.21 ± 0.09 vs $38.56 \pm 0.17^{o}C$), and ratings of perceived exertion; plasma volume expanded 5.2 ± 1.7 %. On day 10, subjects repeated HTT; day 1 vs day 10 HR were statistically similar (143 ± 6 vs 137 ± 6 beats$\cdot min^{-1}$, $p > .05$) but Tre decreased significantly (37.7 ± 0.1 vs $37.5 \pm 0.1^{o}C$, $p < .05$). Group mean HTT composite score (day 1 vs day 10) was unchanged (63 ± 5 vs 72 ± 6, $p > .05$), and individual composite scores indicated that HTT did not accurately measure HR and Tre trends at $41.2^{o}C$ in 6 out of 14 subjects. Among the physical characteristics of subjects, only VO_2max

correlated strongly ($r^2 = .74$, $p < .001$) with HTT, indicating a large aerobic component. We concluded that HTT is not a substitute for classical heat tolerance tests conducted at high ambient temperatures. HTT is apparently most useful in patient or at-risk populations in which preliminary or gross distinctions between heat tolerant and heat intolerant individuals are required.

KEY WORDS: body temperature, acclimatization, heart rate, exertion, heat exhaustion.

Introduction

Tests which predict heat tolerance practically and validly have great potential in industrial, military and clinical settings. Such heat tolerance tests were first designed in the 1930s for use with mine recruits in South Africa (Dreosti 1935; Wyndham 1953) to separate heat tolerant from heat intolerant workers, but required heated, climatically controlled facilities which precluded widespread use. More recently, the Israeli research team of Shvartz et al. (1977b) set out to determine if heat tolerance could be predicted by a simple exercise test performed at room temperature. They reported that a temperate environment heat tolerance test (HTT) was able to distinguish former heat stroke patients from heat acclimatized and unacclimatized individuals. Their HTT involved bench stepping for 15 min in a room maintained at 23°C dry bulb, 16°C wet bulb.

Our interest in HTT originated from a consideration of the following three factors. First, if HTT accurately and precisely reflected changes in heat tolerance, HTT could be utilized in military units in assessing, readiness and/or risk for duty in hot environments, in identifying individuals who require cautious exposure to heat, in screening procedures at military induction centers, and in assessing the heat intolerance status of former heat injury patients. Second, the work of Strydom and Williams (1969) and Wyndham (1973) previously indicated that heat tolerance can best be measured by using high thermal stress and an exercise duration/intensity which stresses subjects for extended periods (e.g. 4 hr of bench stepping exercise, s Shvartz et al. 1977b and Shapiro et al. 1979). Their work suggested that HTT, conducted under temperate conditions, might not be as valid a tool as heat tolerance tests which are conducted under high thermal stress and prolonged work loads. Third, Shvartz et al. (1977b) did not publish individual pre-acclimatization and post-acclimatization HTT scores or anthropometric data. Because it was not clear whether HTT was sensitive enough to track acute changes in heat tolerance, we planned to induce measurable HR and Tre adaptations in our test subjects by using heat acclimation as the stimulus. Therefore, the purpose of this investigation was to evaluate the ability of HTT to measure acute changes in HR and Tre induced by heat acclimation procedures, thereby revealing its validity and sensitivity as a heat tolerance screening device.

Methods

An independent evaluation of HTT was conducted during winter and spring months, following the protocol of Shvartz et al. (1977a, 1977b) with minor revisions. The subjects were 14 healthy, unacclimatized males free from obvious physical defect, having the mean (± SE) characteristics
TABLE 1 described in Table 1. Surface area was calculated using the

technique of DuBois and DuBois (1915). Shvartz et al. (1977b) indicated that HTT may apply to men aged 17-35 years; the subjects in this investigation were all within this age span, except subject C (36 yr) and subject M (46 yr). Prior to HTT, a maximal oxygen consumption (VO_2max) test was performed by each subject, using a modification of the procedure described by McArdle et al. (1973).

Day 1. All subjects bench stepped (30 cm high, 27 steps/min) for 15 min in a temperate environment maintained at 23.2 ± 0.5°C dry bulb, 14.9 ± 0.5°C wet bulb, and 0.1 ± 0.02 $m \cdot min^{-1}$ wind velocity. Before, and at 15 min of exercise, measurements of heart rate (HR), rectal temperature (Tre), oxygen consumption (VO_2), rating of perceived exertion (RPE), and sweat rate (SR) were taken. A composite score was calculated for each subject, as originally described in Table 3 of Shvartz et al. (1977b) using final HR, final Tre, and the following equation:

$$\text{composite score} = \frac{\text{HR score} + \text{Tre score}}{2} \qquad \text{(eq. 1)}$$

HR was measured using an ECG telemetry system (Hewlett Packard). Tre were recorded to the nearest 0.1°C from a rectal probe inserted 8 cm beyond the anal sphincter. Expired respiratory gases were sampled by a computerized on-line system which included a gasmeter (Parkinson-Cowan), oxygen analyzer (Applied Electrochemistry, model SMA) and carbon dioxide analyzer (Beckman, model LB2). Gas analyzers were calibrated prior to each trial using a known gas mixture. Sweat rate was measured locally via a dew point sensor (Graichen et al. 1982), and was measured for the entire body by using body mass differences (corrected for water intake and urinary output) from pre to post trial. RPE (Borg 1970) was measured using the Borg scale (6 - 20 points).

Days 2 - 9. To induce measurable changes in heat tolerance, eight days of heat acclimation were undertaken by all subjects. Each daily trial consisted of 100 min of intermittent exercise, during nine work-rest cycles of 5-10 min each. This exercise protocol, different from the one used by Shvartz et al. (1977a, 1977b), was identical to that used in another investigation (Armstrong et al. 1986) which simulated self-paced running in the heat. Subjects self-selected the treadmill speed at the beginning of each exercise bout, and mean ($\pm$ SE) exercise intensities ranged across days from 63.0 $\pm$ 2.8 to 69.1 $\pm$ 3.1 % VO_2max. During daily heat acclimation trials (41.2°C $\pm$ 0.3 dry bulb, 28.4 $\pm$ 0.3°C wet bulb, 0.10 $\pm$ 0.02 $m \cdot min^{-1}$ wind velocity) HR, Tre, VO_2, RPE, and SR were regularly monitored, using the techniques described above for day 1. Resting blood samples were taken from an antecubital vein (days 2, 5, 9) after a standardized 20 min postural equilibration period in the heat, and were analyzed for hematocrit (microhematocrit) and hemoglobin (cyanmethemoglobin technique, Hycel). Changes in resting (pre-exercise) plasma volume (%ΔPV) were calculated between days using the method of Dill and Costill (1974).

<u>Day 10</u>. All subjects repeated procedures conducted on day 1, as described above.

Statistical significance was calculated using the appropriate paired t-tests and ANOVA, at the 0.05 confidence level. All results were expressed as mean ($\pm$ SE). Correlation coefficients were calculated for the relationships between composite scores on day 1 and day 10 and the following subject characteristics: age, height, weight, surface area, surface area-to-mass ratio, estimated % body fat, and VO_2max.

Results

TABLE 2,3

Tables 2 and 3 describe the measurements which summarily indicate that this group of 14 subjects exhibited significant improvements in heat tolerance as a result of 8 days of heat acclimation trials. Mean resting (pre) PV expanded 5.2 $\pm$ 1.7 % by day 9, but this level had already been reached on day 5 (+ 5.9 $\pm$ 2.6 %). Table 3 indicates that mean final HR fell from 170 $\pm$ 3 (day 2) to 144 $\pm$ 5 (day 9) beats$\cdot$min^{-1} and that mean final Tre decreased from 39.21 $\pm$ 0.09 to 38.56 $\pm$ 0.17°C during heat acclimation trials. Neither whole-body SR nor local SR were altered significantly by 8 days of heat exposure. This observation has been made previously during other 8 day heat acclimation protocols (Armstrong et al. 1985), and is not surprising in view of the fact that SR is not fully increased until after 10 days of heat acclimation trials (Wyndham et al. 1968).

RPE measured during exercise periods 2, 5, 7 and 9 were significantly reduced (day 2 vs day 9) as a result of heat acclimation trials. Final VO_2 did not change during 8 days of heat acclimation trials.

A composite score of 75 points has been defined by Shvartz et al. (1977b) as the score which indicated that subjects were heat acclimatized. The HTT composite scores (eq. 1) for each subject on days 1 and 10 are compared to responses during heat acclimation trials in Table 3. The group mean composite score on day 1 was 63 $\pm$ 5 and on day 10 was 72 $\pm$ 6. After 8 days of heat acclimation (day 10), only 8 out of 14 subjects reached a composite score of 75 points. In addition, Table 3 indicates that 3 subjects had lower composite scores on HTT (subjects E, H and I) and that 2 subjects had the same scores (subjects F and M), after 8 days of heat exposure (day 10).

Bench stepping exercise (days 1 and 10) during HTT was conducted at 67 $\pm$ 3 % VO_2max, and was rated as 11 $\pm$ 4 ("fairly light") on the Borg scale of RPE. An analysis of all HTT physiological measurements on days 1 and 10 verified that final HR and final Tre were better predictors of day 2 and 9 responses in the heat than were ΔHR and ΔTre, as Shvartz et al. (1977a) had earlier indicated.

When all subject characteristics (Table 1) were statistically correlated with composite scores, only VO_2max on day 1 was significantly related to the composite score ($r^2 = 0.74$, $p < .001$). This relationship is illustrated in

FIG. 1 Figure 1. Interestingly, surface area-to-mass ratio (Table 1), which Epstein et al. (1983) have reported to be an important predictor of heat intolerance, was weakly correlated with HTT scores on day 1 (r^2 = .03) and day 10 (r^2 = .29).

Discussion

Shvartz et al. (1977b) have claimed that heat tolerance can accurately be predicted from HR and Tre responses to exercise in a temperate environment. The purpose of the present investigation was to evauate this claim by measuring the ability of HTT to track acute individual changes in heat tolerance. Statistically significant adaptations in HR and Tre during exercise in the heat (day 2 vs 9) were induced by eight days of heat acclimation trials (Tables 2 and 3). Although HTT should have reflected these heat tolerance improvements in our 14 subjects, HTT did not accurately track HR or Tre adaptations observed in the heat and resulted in fallacious conclusions in the following four ways:

1. Shvartz et al. (1977b) indicated that a subject who earned a 75 point composite score would show physiological responses typical of acclimatized men. Four of our 14 unacclimated subjects (subjects A, D, I, K) scored at least 75 points on day 1 (comment #1 in Table 3), prior to heat acclimation trials. Such a classification, made prior to heat acclimation, might cause an individual to be subjected

to inappropriately high levels of exercise-heat stress. For example, subject D exhibited a Tre decrease of 1.03°C during heat acclimation trials, yet could have been classified as "heat acclimatized" on day 1 (HTT composite score of 85). Similarly, subject I showed a HR reduction of 33 beats·min^{-1} as a result of heat acclimation trials, but also could have been classified as "heat acclimatized" on day 1 (composite score of 85). It was not surprising to find that subjects I and K had the highest VO_2max values (Table 1). The influence of aerobic capacity on HTT composite scores is discussed below.

2. Subjects K, L and N (comment #2 in Table 3) exhibited minor or no improvements in either HR or Tre in the heat, yet these three improved their scores on HTT (+5, +20 and +10, respectively) and scored above a 75 point composite score on day 10, indicating "heat acclimatization" according to Shvartz et al. (1977b). None of the physical characteristics described in Table 1 distinguished subjects K, L and N from the other subjects.

3. Three of the subjects who exhibited the greatest improvements in HR and Tre responses in the heat (comment #5 in Table 3), actually had equivalent (subject E) or lower (subjects H and I) HTT scores (day 1 vs 10).

4. The lowest HTT composite score during this investigation (25 points on day 10) was measured in subject H, who paradoxically had scored 40 on day 1 and had exhibited large HR and Tre decreases (45 beats·min^{-1} and

1.24°C) in the heat. The HR of subject H increased during HTT from 70 to 173 on day 1 and increased from 72 to 172 on day 10, essentialy equivalent HR increases of 103 and 100 beats·min^{-1}. His Tre during HTT increased from 37.2 to 37.8 on day 1 and increased from 37.5 to 38.1 on day 10, identical Tre increases of 0.6°C. Composite scores of 40 points (day 1) and 25 points (day 10) were calculated, however, because final HR and Tre values were utilized in determining scores, as prescribed in Table 3 by Shvartz et al. (1977b). The final Tre value of 38.1 on day 10 resulted in a deceptively low composite score, and illustrates a disadvantage of the method used to calculate the composite score (eq. 1).

Shvartz et al. (1977b) did not report individual VO_2max values of their subjects, but our statistical correlations (Fig. 1) indicated that HTT contained a large aerobic component. This is not surprising, because heart rate during submaximal exercise is a reflection of maximal aerobic capacity, and is only partially related to heat tolerance (Hausmann et al. 1966). In this investigation, HTT (23.2°C) did not accurately measure HR and Tre changes observed in the heat (41.2°C), in opposition to previous findings (Shvartz et al. 1977a). In this respect, HTT is similar to a gross prediction of VO_2max from heart rate measured during submaximal exercise. Such a predition is not a valid substitute for the direct measurement of VO_2max (Kasch 1984). Shvartz et al. (1977b) also did not report individual surface area-to-mass ratios of their subjects.

Heat intolerance has been linked to factors such as: compromised cardiovascular function (Burch 1956; Robinson et al. 1976), low VO_2max (Shvartz et al. 1977b), poor transfer of heat from the body's core to the skin (Shapiro et al. 1979), low work efficiency and low body surface area-to-mass ratio (Epstein et al. 1983), as well as low sweat sensitivity (Robinson et al. 1976). HTT (23.2°C) does not address all of these factors adequately because it does not involve thermal stress in the way that standardized heat tolerance tests do (Strydom et al. 1969; Shapiro et al. 1979). Although we do not doubt that heat intolerant individuals attain low composite scores on HTT (Shvartz et al. 1977b), low scores on HTT clearly are not proof of heat intolerance. Indeed, Shvartz et al. (1977b) reported in their Figure 1 that at least 5 out of 35 unacclimatized subjects scored 30 points or less on HTT. Therefore, we conclude that the primary value of HTT may exist in patient or at-risk populations where (a) gross distinctions between heat tolerant and heat intolerant individuals are required or (b) preliminary indications of heat tolerance are necessary, prior to conducting heat tolerance tests under conditions of high ambient temperatures. In fact, these two applications have been utilized successfully in our laboratory on a patient having miliaria rubra.

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TABLE 1 - SELECTED CHARACTERISTICS OF SUBJECTS

SUBJECT	AGE (yr)	HEIGHT (cm)	MASS (kg)	SURFACE AREA (m^2)	SURFACE AREA / MASS ($cm^{-2} \cdot kg^{-1}$)	$\dot{V}O_{2\,max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
A	28	175.5	74.622	1.90	255	42.26
B	23	169	69.634	1.80	258	38.77
C	36	173	57.967	1.69	292	38.84
D	35	165	65.997	1.73	262	61.60
E	25	177	75.005	1.92	256	43.35
F	21	183.5	82.478	2.05	249	47.40
G	28	171	66.934	1.78	266	43.60
H	26	185	101.781	2.26	222	40.95
I	19	183	73.114	1.94	265	48.68
J	32	179	85.829	2.05	239	43.11
K	25	187	79.003	2.04	258	60.87
L	22	184	88.262	2.11	239	49.07
M	46	165	85.616	1.93	225	40.42
N	32	180	110.517	2.29	207	41.40
$\bar{x}$	28.4	177	79.771	1.96	250	45.74
$\pm$ SE	1.9	2	3.784	0 05	6	1.96

TABLE 2 - INDICES OF HEAT ACCLIMATION (AT 41.2°C), MEASURED ON THE FIRST (DAY 2) AND LAST (DAY 9) DAYS OF HEAT ACCLIMATION TRIALS.+

MEASUREMENT	UNIT	DAY 2	DAY 9	STATISTICAL SIGNIFICANCE
Resting plasma volume (PRE)	% Δ PV		5.2 ± 1.7 ++	
RPE - period 2		8 ± 1	7 ± 1	*
- period 5		11 ± 1	10 ± 1	*
- period 7		13 ± 1	11 ± 1	*
- period 9		14 ± 2	11 ± 2	*
Final sweat rate - whole body	$g \cdot m^{-2} \cdot hr^{-1}$	401 ± 35	380 ± 45	
- local	$mg \cdot cm^{-2} \cdot min^{-1}$	6.43 ± 0.96	5.76 ± 0.72	
Final $\dot{V}O_2$	$ml \cdot kg^{-1} \cdot min^{-1}$	35.33 ± 1.06	35.91 ± 0.82	

+ - See table 2 for mean (± SE) HR and Tre data on days 2 and 9

++ - compared to day 2

* - $p < .05$

TABLE 3 - COMPARISON OF HR (BEATS·MIN^{-1}) AND Tre (^{o}C) AT THE END OF HEAT ACCLIMATION TRIALS (DAYS 2 AND 9) AND TT (DAYS 1 AND 10). COMPOSITE SCORES FOR TT ARE ALSO GIVEN.

SUBJECT	HEAT ACCLIMATION TRIALS[+]				TEMPERATE ENVIRONMENT HEAT TOLERANCE TEST (TT)[++]							COMMENTS
	FINAL HR		FINAL Tre		FINAL HR		FINAL Tre		COMPOSITE SCORE[+++]			
	DAY 2	DAY 9	DAY 2	DAY 9	DAY 1	DAY 10	DAY 1	DAY 10	DAY 1	DAY 10	CHANGE	
A	163	155	38.85	38.10	135	129	37.4	37.1	80	85	+5	1
B	174	119	38.80	37.58	175	145	37.6	37.4	50	75	+25	3,4,7
C	172	138	39.67	38.67	150	121	37.9	37.3	50	90	+40	3,4,7
D	142	123	39.66	38.63	101	93	37.8	37.7	85	90	+5	1,4
E	181	157	38.63	37.73	162	165	37.3	37.7	60	50	-10	5
F	168	160	39.30	38.30	136	150	37.7	37.2	70	70	0	4,6
G	170	121	39.53	38.07	146	144	38.2	37.6	35	70	+35	3,4,7
H	159	114	39.21	37.97	173	172	37.8	38.1	40	25	-15	3,5
I	183	150	39.47	39.29	127	135	37.2	37.0	85	80	-5	1,3,5
J	179	134	39.18	38.60	165	149	37.6	37.1	55	70	+15	3
K	179	163	39.34	39.31	106	103	37.5	37.3	95	100	+5	1,2
L	175	178	39.54	39.32	132	129	37.8	37.4	65	85	+20	2,7
M	157	145	38.88	38.71	166	161	37.9	37.9	40	40	0	6
N	175	163	38.90	39.62	129	116	37.8	37.7	70	80	+10	2
$\bar{x}$	170 *	144	39.21 *	38.56	143	137	37.7 *	37.5	63	72	9	
± SE	3	5	0.09	0.17	6	6	0.1	0.1	5	6	4	

(continued)

TABLE 3 (continued from previous page)

+ - measured at minute 100 of trials ($41.2 \pm 0.5^{\circ}C$ dry bulb)

++ - measured at minute 15 of trials ($23.2 \pm 0.5^{\circ}C$ dry bulb)

+++ - see equation 1 in text

* - $p < .05$

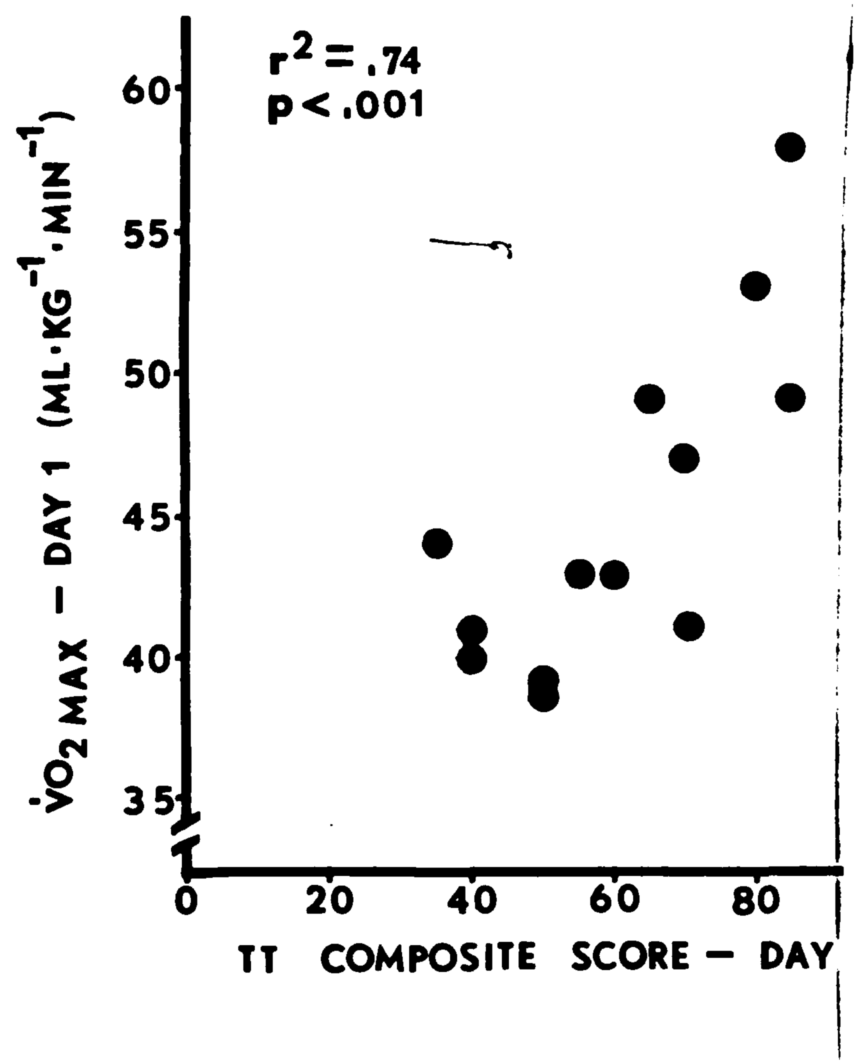
Comments

1. Exceeded 75 point composite score (indicating heat acclimatization) on day 1 of TT, prior to heat acclimation trials.
2. Minor or no change in either HR or Tre responses in the heat resulted from 8 days of heat acclimation.
3. Exhibited HR decrease of at least 30 beats$\cdot$min^{-1} in the heat (day 2 vs day 9).
4. Exhibited Tre decrease of at least $1.0^{\circ}C$ in the heat (day 2 vs day 9).
5. Composite score on TT decreased after 8 days of heat acclimation.
6. Composite score on TT was unchanged after 8 days of heat acclimation.
7. Composite score on TT increased by 20 points or more after 8 days of heat acclimation.

<u>Legend</u>

Figure 1 - Relationship between VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$) and HTT composite score on day 1.

FIGURE 1


$r^2 = .74$
$p < .001$
60
55
50
45
40
35
0
20
40
60
80
$\dot{V}O_2$ MAX – DAY 1 (ML·KG^{-1}·MIN^{-1})
TT COMPOSITE SCORE – DAY

END
11-86
DTIC